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Review

Low back pain and postural sway during quiet standing with and without sensory manipulation: A systematic review

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ABSTRACT

A previous review concluded that postural sway is increased in patients with low back pain (LBP). However, more detailed analysis of the literature shows that postural deficit may be dependent on experimental conditions in which patients with LBP have been assessed. The research question to be answered in this review was: "Is there any difference in postural sway between subjects with and without LBP across several sensory manipulation conditions?". A literature search in Pubmed, Scopus, Embase and PsychInfo was performed followed by hand search and contact with authors. Studies investigating postural sway during bipedal stance without applying external forces in patients with specific and non-specific LBP compared to healthy controls were included. Twenty three articles fulfilled the eligibility criteria. Most studies reported an increased postural sway in LBP, or no effect of LBP on postural sway. In a minority of studies, a decreased sway was found in LBP patients. There were no systematic differences between studies finding an effect and those reporting no effect of LBP. The proportion of studies finding between-group differences did not increase with increased complexity of sensory manipulations. Potential factors that may have caused inconsistencies in the literature are discussed in this systematic review.

1. Introduction

Approximately 60–80% of all people suffer from low back pain (LBP) at some time in their life [1]. Although patients often recover rapidly, residual symptoms and new episodes are not uncommon [2]. Recurrent LBP may interfere with different aspects of peoples' lives and LBP is the most common factor causing activity limitation in people below the age of 45 [2].

Balance, a foundation for most activities of daily living, may be affected in people with LBP. Balance can be tested by measuring movement of the body's center of mass relative to the base of support in standing under the instruction to stand relaxed or minimize movement. The movement that occurs in such cases, usually referred to as postural sway, can be approximated to as the movement of a single inverted pendulum rotating around the ankle joints. The trajectory of the center of pressure of the ground reaction force under the feet (COP) is in this case strongly related to the movement of the body's center of mass [3,4]. Since the COP trajectory is easy to measure using a force plate, COP data are commonly used to study balance control.

Limiting postural sway requires adequate trunk control, since any rotation around the ankle joints will induce variation in gravitational moments around the spine that have to be controlled by trunk musculature to maintain trunk alignment. In addition small deviations from the single inverted pendulum approximation do occur, as postural sway comprises trunk movements that are coordinated with movements of the lower extremities to reduce excursion of the body's center of mass [5–7].

Byl and Sinnott [8] were the first to investigate balance control in patients with LBP, by measuring COP movements. Subsequently, many comparable studies have been published and a recent review concluded that there is consistent evidence that LBP coincides with increased sway amplitude and/or sway velocity [9]. However, a more detailed analysis of the original studies suggests that findings within studies may not be consistent, with effects found in some conditions and not in other conditions. For example, Mientjes and Frank [10] tested subjects in a range of conditions, comprising standing on firm and unstable surfaces, with eyes open and closed,

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standing upright and leaning forward, with head upright and tilted backward. Differences between groups were found only when visual information was removed (eyes closed) and/or when vestibular information was manipulated (head tilt). This suggests that increased postural sway may not be present in LBP as consistently as suggested and in fact such dependence on experimental conditions may provide insight into the mechanism underlying changes of balance control in LBP.

Several factors associated with LBP are likely to affect postural control, for example, impairments of lumbar proprioception [11–13]. Increased postural sway when visual or vestibular input is removed or manipulated in subjects with LBP compared with healthy subjects would support the role of such impairments. Furthermore, impaired motor control of the trunk, as a result of LBP has been suggested to determine increased postural sway [12,14]. Radebold et al. [14] found a correlation between poor balance control in an unstable sitting position and delayed trunk muscle responses after a sudden release perturbation in patients with idiopathic LBP, and Leinonen et al. [12] reported a similar relationship in sciatica patients. Note that delayed muscle responses could actually be the result of sensory impairments. The aim of the present systematic review, therefore, was to determine whether individuals with LBP show more or faster postural sway across several sensory manipulations.

As suggested above, interaction of several experimental manipulations with the presence of LBP may elucidate underlying impairments. Furthermore, methodological quality and type of LBP (i.e. severity, disability and origin) may affect results. The effect of these variables will therefore be investigated in this review.

2. Materials and methods

2.1. Search strategy

Four electronic databases, i.e. Pubmed (1966 to March 2011), Scopus (1960 to March 2011), Embase (1974 to March 2011) and PsychInfo (1800 to March 2011), were searched. The key words used to guide the search were back pain; sway; balance; posture or stabil*. To supplement the literature search, hand search was performed by reviewing the reference lists of included articles. In addition, the corresponding authors of articles selected for inclusion were contacted by email to ask if they knew any (un)published data that was not included in the list of articles. The search strategy was limited to articles written in English.

2.2. Study selection

Two reviewers (MM and PC) independently selected the eligible studies based on inclusion/exclusion criteria detailed below. All studies that investigated bipedal standing postural tasks in patients with specific or nonspecific LBP compared with healthy subjects were considered for inclusion in the present study. All studies had to assess postural sway without applying external forces; meaning that studies which used platform translations and rotations were excluded, while studies which applied sensory and surface-type manipulations were included. Only studies using sway amplitude or sway velocity were included. In case of disagreement, consensus was reached by consulting a third reviewer (JvD).

2.3. Methodological quality

Since no methodological quality scale is available for the assessment of comparative studies on postural sway, we designed a checklist considering internal, statistical and external validity of the included studies (Table 1).

The quality score for each domain was calculated by dividing the number of items with positive points by the total number of items multiplied by 100. Domain scores were averaged to obtain an overall measure of quality. Quality of studies was assessed by two reviewers (MM and PC) independently and disparities were resolved by consulting a third reviewer (JvD). Because, the checklist was not a standardized and accepted tool, no studies were excluded based on methodological quality. However, methodological quality differences might explain possible heterogeneity between studies. Therefore, methodological quality was compared between the studies finding and not finding differences in postural sway between patients with LBP and controls.

2.4. Data extraction

Data extraction was performed by one reviewer (MM) and confirmed by another (PC). The following information was extracted from full-text articles of all included studies: the authors' name, the characteristics of the samples, including inclusion/exclusion criteria of patients with LBP and the number and gender of subjects in each group, conditions in which postural control was assessed, outcomes measured and key findings.

We categorized results of all studies according to the sensory manipulations applied (i.e. visual, proprioceptive, vestibular or no manipulation), to assess the effect of these manipulations on postural sway in LBP subjects. Furthermore, because severity of LBP may affect study results, we extracted information on pain intensity, disability and type of LBP (specific or non-specific).

3. Results

3.1. Literature search

The search yielded a total of 5284 potentially relevant studies after removal of duplicates. After application of inclusion/exclusion criteria to title and abstracts, 34 studies remained. Detailed review of full texts led to excluding 13 studies due to assessment of sway during single-leg stance [15–17] or quiet stance with shoulder flexion [18], the lack of a control group [19–21], use of a dynamic platform for assessment of postural sway [22] or external perturbations [23,24]. Furthermore, studies were excluded from the review due to use of COP parameters not reflecting sway amplitude or velocity [25], and including individuals with general musculoskeletal pain [26] or experimentally induced

Table 1
Methodological quality checklist.

	Internal validity	Scoring
1	Reliability of the dependent variables	A positive point was assigned if a minimum sampling duration of 90 s and/or 3–5 repetitions was used.
2	Clear presentation of balance assessment	A positive point was assigned if replication of the experiment is possible based on the information in the article.
3	Correction for confounding effect on dependent variables	Positive points were assigned if confounders (i.e. age, gender, body height, body mass and physical activity) were taken into account, or appropriate matching on these variables was performed.
	Statistical validity	Scoring
4	The use of appropriate statistical tests	A positive point was assigned if appropriate tests were used to assess differences in balance.
5	Adequacy of the number of subjects included in the study	A positive point was assigned if a minimum of 20 subjects per group were included.
	External validity	Scoring
6	Sufficient information about the subjects' characteristics	Positive if information about age, gender, body length, body mass, physical activity and type-, duration-, and severity of LBP and level of disability was provided.

Table 2
Data extracted from all included studies.

First author	Inclusion/exclusion criteria	LBP group	Healthy group	Conditions	Outcome measures	Findings
Byl and Sinnott [8]	LBP patients with acute bulging disks, narrowed disk space, old disectomy, old herniated disk, acute strain, chronic strain and sacroiliac dysfunction. Free from systemic neuromusculoskeletal diseases or mental disorders.	20	25	SS–EO–HS SS–EC–HS SS–EC–HT US–EC–HS US–EC–HT Tandem stance: US–EC–HS	Body sway	Greater body sway in SS–EO–HS and SS–EC–HS
Luoto et al. [40]	Moderate LBP patients with limitations in work and daily living and age between 20 and 60 years. Free from cardiovascular disease or psychiatric disorders. Not reacted favorably to outpatient physical therapy. Not being candidate of immediate surgery. Severe LBP patients with clinical and/or neurophysiologic signs of sciatic irritation.	Moderate LBP: 33 male 35 female Severe LBP: 18 male 13 female	33 male 29 female	EO	Body sway velocity	Among women only, significantly higher body sway velocity in patients with severe LBP compared to moderate LBP and healthy groups
Dvir et al. [29]	Patients with disk protrusion or herniation, degenerative changes or idiopathic LBP. LBP duration ≥ 6 months. No acute pain at the testing day. No history of pain extending mid-thigh level. Free from neuromuscular, systemic or vestibular disorders, cervical injury, ankle instability or using medicine affecting central nervous system.	18 male 13 female	15 male 14 female	SS–EO SS–EC	Body sway	Greater body sway for LBP patients compared to healthy people in SS-EC condition
Takala et al. [44]	Free from neurological diseases and chronic arthritis, pain radiating below the knee (sciatic LBP) or other types of LBP. LBP duration ≥ 30 days. Present LBP patients with pain present at the testing day; past pain possible in low back or lower extremity.	Present LBP: 27 male 16 female Past LBP: 40 male 28 female	194 male 71 female	EO EC	Body sway total and in AP and ML direction, Body sway velocity total and in AP and ML	In EO, greater total body sway and body sway in ML direction for patients with present LBP and past LBP compared with non-symptomatic people
Luoto et al. [39]	Moderate LBP patients with limitations in work and daily living and age between 20 and 60 years. Free from cardiovascular disease or psychiatric disorders. Not reacted favorably to outpatient physical therapy. Not being candidate of immediate surgery. Severe LBP patients with clinical and/or neurophysiologic signs of sciatic irritation.	Moderate LBP: 33 male 35 female Severe LBP: 18 male 13 female	32 male 29 female	EO–ES vibration EC–ES vibration EO–GC vibration EC–GC vibration	Body sway velocity	Among both men and women, no significant difference between the two groups of LBP patients and healthy controls
Alexander and LaPier [30]	Unilateral LBP duration ≥ 3 months. Pain-free over the previous 4 weeks. Free from uncorrected vision or other visual impairments, diagnosed vestibular or neurologic disorder, alcoholic consumption within 12 h of testing, uncontrolled metabolic disorder, history of dizziness or unexplained falls within the past 6 months, medications affecting balance, any lower extremity pathology, decreased sensation or unresolved musculoskeletal injury.	7 male 8 female	7 male 8 female	EO EC	Body sway total and in AP and ML direction	In EO, greater total body sway and body sway in AP direction and in EC, greater total body sway and body sway in AP and ML direction in LBP patients
Mientjes and Frank [10]	Back pain in lumbar region. LBP duration ≥ 3 months. No history of specific balance disorders, spinal surgery and hip/knee/ankle/foot problems.	5 male 3 female	5 male 3 female	SS–EO–HN SS–EC–HN SS–EO–BHT SS–EC–BHT SS–FL–EO–HN SS–FL–EC–HN US (foam)–EO–HN	Body sway in AP and ML direction	Increased body sway in AP direction for LBP patients in SS–EC–HN and SS–FL–EC–HN Greater body sway in ML direction for LBP patients in SS–EC–HN, SS–EO–BHT, SS–EC–BHT, SS–FL–EO–HN and SS–FL–EC–HN

Table 2 (*Continued*)

First author	Inclusion/exclusion criteria	LBP group	Healthy group	Conditions	Outcome measures	Findings
Kuczynski and Paluch[28]	Pain present in back and lower extremities with positive Lasegue' sign Average LBP duration of 3 months Pain intensity between 5 and 10 on VAS Moderate LBP with pain intensity between 5 and 8 on VAS Severe LBP with pain intensity between 9 and 10 on VAS	Moderate LBP: 16 Severe LBP: 14	10 male 9 female	EO	Body sway, Body sway velocity	Larger body sway in frontal plane in patients with severe LBP only
Hamaoui et al. [35]	Nonspecific LBP ≥ 3 months Free from any associated disease	10 male	10 male	EO	Body sway in AP and ML direction	While breathing normally, larger body sway in AP and ML direction for LBP patients compared to healthy individuals
Grimstone and Hodges [34]	Episodic LBP ≥ 18 months with at least one episode per year Minimal or no pain with no medication at the time of testing Insidious LBP leading to functional limitation and seeking medical or allied health treatment No history of respiratory or neurological disease, lower limb injuries, uncorrected visual impairment, previous spinal surgery, spinal deformity, dizziness or fall or undergoing abdominal or back muscle training in the past 3 months	10	10	EO	Body sway in AP direction	While breathing normally, larger body sway in LBP patients compared to healthy people
Leinonen et al. [12]	Prolonged LBP with sciatica Candidates of discectomy	15 male 5 female	10 male 5 female	EO EC	Body sway velocity	Larger body sway velocity in EO and EC in LBP patients compared to healthy people
Mok et al. [42]	LBP duration ≥ 18 months At least 1 episode of LBP in the last 6 months or pain with semicontinuous nature LBP requiring treatment or leave from work Free from LBP with a neuromusculoskeletal origin, sensory or neurologic disorders, previous surgery, structural defect of spine, lower limb pathology, use of medication affecting balance	24	24	FS–EO FS–DL FS–EC NS–EO NS–DL NS–EC	Body sway in AP direction, Body sway velocity	Decreased body sway velocity in LBP group compared with healthy individuals
Brumagne et al. [13]	Mostly mechanical LBP	Young LBP: 10 Elderly LBP: 10	Young healthy: 10 Young healthy: 10	EC: No-vibration TS vibration TA vibration PS vibration	Body sway in AP direction	In no-vibration, larger body sway in LBP patients compared to healthy individuals
Hamaoui et al. [36]	LBP duration ≥ 3 months. No history of spinal deformity, neurological deficits, osteoarticular and vestibular diseases, spinal surgery and use of medications.	10 male	10 male	FA–EO FA–EC FC–EO FC–EC	Body sway in AP and ML direction	Greater body sway in AP direction in LBP patients compared to healthy people in all conditions with the exception of FS–EO
della Volpe et al. [33]	LBP duration > 6 months. No radiation of pain to buttock. No history of sciatica or radicular pain. Free from vestibular, neurological and hip/knee/ankle/foot disorders.	7 male 5 female	12	EO EC Movable visual surround	Body sway in AP and ML direction, Body sway velocity in AP and ML direction	No significant difference between the two groups for any outcome measure
Brumagne et al. [31]	Nonspecific LBP > 6 months At least 3 recurrent episodes of LBP No history of vestibular disorder, neurological or respiratory disease, previous spinal surgery, radicular pathology or neck problems	56	33	EO EC	Body sway	No significant difference between the two groups
Brumagne et al. [32]	Nonspecific LBP > 6 months At least 3 recurrent episodes of LBP No history of vestibular disorder, neurological or respiratory disease, previous spinal surgery, radicular pathology, lower limb or neck problems Pain-free at the time of testing	7 male 14 female	11 male 13 female	SS: EO EC US (foam): EO EC	Body sway in AP direction	During standing on US with EC, larger body sway in patients with LBP compared to controls

Table 2 (*Continued*)

First author	Inclusion/exclusion criteria	LBP group	Healthy group	Conditions	Outcome measures	Findings
Harringe et al. [37]	Top-level gymnasts Free from scoliosis No pain or injury interfering with test performance	11 female	18 female	SS: EO EC US (foam): EO EC	Body sway total and in AP and ML directions	No significant difference between the 2 groups
Lafond et al. [38]	Mechanical LBP ≥ 6 months No radiation of pain beyond buttock Normal neurological exam Free from vestibular or neurological problems, history of dizziness and use of medicine affecting balance	12	12	EO	Body sway total and in AP and ML direction, Body sway velocity in AP and ML direction	Larger body sway velocity in AP direction, body sway total and body sway in AP direction in patients with LBP compared to controls Lower body sway and sway velocity in ML direction in patients with LBP compared to controls
Xie et al. [46]	Patients with recurrent episodes of nonspecific LBP At least two episodes of LBP over the last 6 months Age between 25 and 55 and body mass index <35 Able to do daily living and job activities No history of red flags, neuromuscular disorders, specific LBP, surgery and cervical pain Mild pain at the time of testing	10	10	FA–EO FA–EC FC–EO Semi-tandem stance: EO	Body sway in AP and ML direction, Body sway velocity in AP and ML direction	In FC–EO, larger body sway and sway velocity in AP direction in LBP patients compared to healthy individuals
Salavati et al. [43]	Patients with episodic LBP ≥ 12 months No history of serious spinal pathology, nerve root pain, spinal surgery, spinal structural deformity No history of pain extending gluteal fold VAS ≤ 2 at the testing day No history of uncorrected vision impairment, vestibular or respiratory disorder, auditory or cognitive deficit, diabetes, lower limb pathology, pregnancy and using medicine affecting balance	13 male 9 female	13 male 9 female	SS–EO SS-EC US (foam)–EC	Body sway velocity	Smaller body sway velocity in LBP group compared with healthy individuals
Mann et al. [41]	Patients with chronic non-specific LBP. LBP duration ≥ 3 months. Not involved in regular physical activity during the 6 months prior to testing.	10 female	10 female	EO EC	Body sway in AP and ML direction, Body sway velocity	In EO and EC, larger body sway in AP and ML directions in LBP group compared to healthy individuals In EC but not EO, larger body sway velocity in LBP patients compared to healthy people
Yahia et al. [45]	LBP ≥ 3 months without radiculopathy Age between 20 and 55 years VAS ≤ 5 Free from neurological conditions, scoliosis, unequal length > 1 cm, flat or cavus foot, vestibular or visual impairment, cardiac disease, psychiatric disorder, osteoarthritis of hip or knee	6 male 24 female	6 male 24 female	SS: EO EC US: EO EC	Body sway	During standing on US with EO and EC, larger body sway in LBP group compared to healthy individuals

Abbreviations: AP: antero-posterior; BHT: backward head tilt; DL: dim light; EC: eyes-closed; EO: eyes-open; ES: erector spinae; FA: feet apart; FC: feet close together; FL: forward lean; FS: flat surface; GC: gastrocnemius; HN: head normal; HS: head still; HT: head turn; LBP: low back pain; LOS: limit of stability; ML: medio-lateral; MF: multifidus; NS: narrow surface; PS: paraspinal; SS: stable surface; TA: tibialis anterior; TS: triceps surae; US: unstable surface.

rather than true LBP [27]. The hand search of reference lists produced two additional articles [28,29]. Contacting the corresponding authors did not yield additional (un)published data. In total, 23 studies [8,10,12,13,28–46] met the inclusion criteria.

3.2. Description of included studies

The characteristics of studies eligible to answer this question have been summarized in Table 2. Center of pressure (COP) data were employed in all studies [8,10,12,13,28–46]. To quantify body sway and sway velocity, various parameters were calculated from COP data including maximum amplitude, mean amplitude, range, velocity, root-mean-square and standard deviation amplitude, root-mean-square and standard deviation velocity, area, path length, phase plane portrait, target sway and sway index. COP velocity was the most frequently reported outcome measure. All parameters were categorized into body sway and sway velocity.

To assess the contribution of various sources of sensory feedback (i.e. visual, proprioceptive and vestibular) in maintaining upright posture, sensory information was manipulated in most studies. Occluding and closing the eyes [8,10,12,13,29–33,36,37,39,41–46], dimming of the lights [42] and moving the visual surrounds [33] were used to remove or perturb visual information. Proprioception was perturbed by alteration of shoes or support surface [8,10,32,37,43,45], and by means of muscle vibration [13,39]. Vibrations were applied to triceps surae [13,39], tibialis anterior [13] and paraspinal [13,39] muscles. Vestibular information was challenged by changing head orientation (i.e. turning the head sideways, forward or backward) [8,10].

To quantify severity of pain, a Visual Analog Scale (VAS) was used in 13 studies [10,12,28,31,32,34,38–43,45] out of 14 that reported pain severity. One study [37] used Borg's scale for pain rating. Notably, the severity of pain as measured by VAS (0 [no pain]–10 [maximum pain]) was minimal to moderate (mean 3.7, range 1.5–6.1) [10,12,31,32,38–42,45]. Some studies [34,43] included patients who had no or minimal (VAS < 2) level of pain at the time of testing. One study [44] included patients with a recent history of LBP. Disability was assessed using self-report measures including the Ostwestry Disability Index [10,12,31–33,38–40,45] and the Roland–Morris Disability Questionnaire [10,42,43]. The mean disability scores in all studies reflected moderate disability (mean 23.9% (range 12.6%–38.4%) on the Oswestry Disability Index (0% [no disability]–100% [maximum disability]) and 4.7 (range 3.2–7.5) on the Roland–Morris Disability Questionnaire (0 [no disability]–24 [maximum disability]). Only a few studies measured the level of physical activity using Baecke Habitual Physical Activity Questionnaire (3 [low level of physical activity]–15 [high level of physical activity]) [31,32,34,42]. The total score ranged from 3.2 to 9.1 (mean 7.5), indicating a low to moderate level of physical activity in the groups with LBP.

3.3. Sway and sensory manipulation

Methodological quality of all studies is shown in Table 3. The included studies provide inconclusive evidence as to whether postural sway is different between individuals with and without LBP (Table 4). Overall, the results vary from more postural sway in LBP reported by most researchers, to no between-group difference found in a substantial part of studies, to less sway in LBP in a minority of studies. For instance, when no manipulations were applied, 12 studies found a larger sway in LBP, 9 studies found no effect and 3 studies found reduced sway in LBP.

We compared the proportion of studies finding between-group differences in the two most common experimental conditions, i.e. no-manipulation and eyes-closed conditions. The number of studies showing more or less sway relative to the total number of studies in the no-manipulation condition (15/24, 63%) was similar to that reporting such effects when perturbing visual information (10/17, 59%). Perturbation of visual input generally increases postural sway and it has been suggested that this would increase differences between healthy subjects and individuals with LBP [9,29]. However, the effect of LBP was not more consistent when visual information was perturbed, with 8 studies finding increased sway in LBP, 7 finding no effect and 2 finding less sway in LBP.

Also under perturbations of proprioceptive information, the results were inconsistent with 1 study finding more sway in LBP, and 4 studies finding no between-group difference. Propioception was perturbed by alteration of support surface [10,32,37,45]. In one study proprioception was manipulated by means of muscle vibration [39]. However, no differences in postural sway were found between groups in the vibration conditions.

Seven studies addressed manipulations of proprioception in a condition with eyes closed. Only one study showing no difference between LBP patients and controls when testing on foam with eyes open, did find a difference when testing on foam with eyes closed [32]. Overall results were inconsistent, with 2 studies showing more sway in LBP, 4 studies showing no between-group difference and 1 study showing less sway in LBP.

In one study, individuals with LBP swayed more, when vestibular information was manipulated by a head tilt with eyes closed, but also with eyes open [10]. In another study [8] no effect of LBP was found when the head was tilted, in combination with eyes closed while standing on rigid or foam surface, whereas it did show effects of LBP in unperturbed stance and upright stance with eyes closed.

3.4. Methodological issues

Some quality differences between studies finding a difference and the studies not finding a difference are apparent in Table 4 both for the condition without sensory manipulations and for the conditions with visual manipulations. The overall quality tended to be lower in studies finding a difference. Specifically a small proportion of studies that did find a difference between groups had adequately matched or controlled for age, height, body mass and physical activity. Therefore some of the positive results may be accounted for by bias due these demographic factors.

The effect of LBP on postural sway in those studies that obtained no between-group differences may be missed due to a lack of statistical power. Reliability of the dependent variables and sample size are two factors that can affect statistical power [47]. Surprisingly, the median number of subjects included in the studies finding no difference ($n_{total} = 504$ and $n_{median} = 45$) was higher than in the studies finding increased sway ($n_{total} = 820$ and $n_{median} = 27$). To enhance reliability, it has been recommended to use a minimum sampling duration of 90 s in combination with 3–5 repetitions [48]. Only two studies used a sampling duration ≥ 90 s, one finding a difference [34] and one not finding a difference [37] between groups. Also, 3 out of 12 (25%) studies in the group showing an effect and 2 out of 9 (22%) studies in the group not showing an effect used an appropriate number of trials (3–5).

Also with visual manipulation, the median number of subjects was higher in the studies finding no difference ($n_{total} = 643$ and $n_{median} = 45$) compared to the studies finding a difference ($n_{total} = 266$ and $n_{median} = 33$). Only one study, reporting no effect [37], used trials with a sampling duration ≥ 90 s. Furthermore, 3 out of 8 (38%) studies in the group finding and 1 out of 7 (14%) studies not finding a difference employed 3–5 trials of COP recording.

3.5. Subject population

Back pain intensity and chronicity are two other factors that may affect the results of studies examining sway in LBP. The

Table 3
Quality assessment scale for all included studies.

Authors	Internal validity							Score	Statistical validity		Score	External validity									Score	Total score
	1	2	3A	3B	3C	3D	3E		4	5		6A	6B	6C	6D	6E	6F	6G	6H	6I		
Nies and Sinnott [8]	–	+	–	–	–	–	–	14	+	+	100	–	–	–	–	–	+	–	–	–	11	42
Luoto et al. [40]	–	+	–	–	+	–	–	29	+	+	100	+	+	+	+	–	–	+	+	+	78	69
Dvir et al. [29]	–	+	–	–	–	–	–	14	+	+	100	+	+	–	–	–	+	+	–	–	44	53
Takala et al. [44]	–	+	+	+	+	+	–	71	+	+	100	+	+	+	+	–	–	+	–	–	56	76
Luoto et al. [39]	–	+	–	–	+	–	–	29	+	+	100	+	+	+	+	–	–	+	+	+	78	69
Alexander and LaPier [30]	–	+	+	+	+	–	–	57	+	–	50	+	+	+	–	–	–	+	–	–	44	50
Mientjes and Frank [10]	+	+	+	+	–	–	–	57	+	–	50	+	+	+	–	–	–	+	+	+	67	58
Kuczynski and Paluch [28]	–	–	–	––	–	–	–	0	–	–	0	+	+	+	+	–	–	+	+	–	67	22
Hamaoui et al. [35]	+	+	–	+	–	–	–	43	+	–	50	+	+	+	+	–	+	+	–	–	67	53
Grimstone and Hodges [34]	+	+	+	–	+	+	+	86	+	–	50	+	–	+	+	+	–	+	+	–	67	68
Leinonen et al. [12]	–	+	–	–	–	–	–	14	+	–	50	+	+	+	+	–	+	–	+	+	78	47
Mok et al. [42]	–	+	+	+	+	–	+	71	+	+	100	+	–	+	+	+	+	+	+	+	89	87
Brumagne et al. [13]	–	+	–	–	–	–	–	14	+	–	50	–	–	–	–	–	+	–	–	+	22	29
Hamaoui et al. [36]	+	+	+	+	–	–	–	57	+	–	50	+	+	+	+	–	+	+	–	–	67	58
della Volpe et al. [33]	+	+	+	–	–	–	–	43	+	–	50	+	+	+	–	–	+	+	–	+	67	53
Brumagne et al. [31]	–	+	+	–	+	+	+	71	+	+	100	+	–	+	+	+	+	+	+	+	89	87
Brumagne et al. [32]	–	+	+	–	+	+	+	71	+	+	100	+	+	+	+	+	+	+	+	+	100	90
Harringe et al. [37]	+	+	+	+	+	+	+	100	+	–	50	+	+	+	+	+	–	–	+	–	67	72
Lafond et al. [38]	–	+	+	+	+	+	–	71	+	–	50	+	–	+	+	–	+	+	+	+	78	66
Xie et al. [46]	–	+	+	+	+	+	+	86	–	–	0	+	–	+	+	+	+	–	–	–	56	47
Salavati et al. [43]	+	+	+	+	+	+	–	86	+	+	100	+	+	+	+	–	+	+	+	+	89	92
Mann et al. [41]	+	+	–	+	–	–	+	57	+	–	50	+	+	+	+	+	+	+	+	–	89	65
Yahia et al. [45]	–	+	+	+	+	+	–	71	+	+	100	+	+	+	+	–	–	+	+	+	78	83

1 indicates reliability of outcome measures; 2, clear presentation of balance assessment; 3A, study controls for age; 3B, study controls for gender; 3C, study controls for height; 3D, study controls for body mass; 3E, study controls for physical activity; 4, use of appropriate statistical tests; 5, adequate sample size; 6A, adequate information regarding age; 6B, adequate information regarding gender; 6C, adequate information regarding height; 6D, adequate information regarding body mass; 6E: adequate information regarding physical activity; 6F, adequate information regarding type of LBP; 6G, adequate information regarding duration of LBP; 6H, adequate information regarding severity of LBP; 6I, adequate information regarding level of disability.

Table 4
Quality of study groups reporting increase, decrease or no change of postural sway in individuals with LBP compared to healthy controls in different conditions of sensory manipulation.

Manipulation	No. of studies	Internal validity							Score	Statistical validity		Score	External validity									Score	Total score
		1	2	3A	3B	3C	3D	3E		4	5		6A	6B	6C	6D	6E	6F	6G	6H	6I		
No	24																						
More sway [8,40,30,44,12,28,34,35,36,38,41,46]	12	4	11	6	7	6	4	3	49	10	3	54	11	8	11	10	3	7	9	6	3	64	63
No difference [29,40,10,33,31,32,37,45,46]	9	3	9	7	4	6	5	4	60	8	5	72	9	7	8	6	4	5	7	6	6	74	72
Less sway [42,38,43]	3	1	3	3	3	3	2	1	76	3	2	83	3	1	3	3	1	3	3	3	3	85	81
Visual	17																						
More sway [8,29,30,10,12,13,36,41]	8	3	8	3	4	1	0	1	36	8	2	63	6	6	5	3	1	6	5	3	3	53	51
No difference [44,33,31,32,37,45,46]	7	2	7	7	4	6	6	4	73	6	4	71	7	5	7	6	4	4	5	4	4	73	72
Less sway [42,43]	2	1	2	2	2	2	1	1	79	2	2	100	2	1	2	2	1	2	2	2	2	89	89
Proprioceptive	5				–																		
More sway [45]	1	0	1	1	1	1	1	0	71	1	1	100	1	1	1	1	0	0	1	1	1	78	83
No différence [10,32,37,39]	4	2	4	3	2	3	2	2	64	4	2	75	4	4	4	3	2	1	3	4	3	78	72
Less sway	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Vestibular	1																						
More sway [10]	1	1	1	1	1	0	0	0	57	1	0	50	1	1	1	0	0	0	1	1	1	67	58
No difference	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Less sway	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Visual + proprioceptive	7																						
More sway [32,45]	2	0	2	2	1	2	2	1	71	2	2	100	2	2	2	2	1	1	2	2	2	89	87
No difference [8,39,13,37]	4	1	4	1	1	2	1	1	39	4	2	75	2	2	2	2	1	2	1	2	2	44	53
Less sway [43]	1	1	1	1	1	1	1	0	86	1	1	100	1	1	1	1	0	1	1	1	1	89	92
Visual + vestibular	2																						
More sway [10]	1	1	1	1	1	0	0	0	57	1	0	50	1	1	1	0	0	0	1	1	1	67	58
No difference [8]	1	0	1	0	0	0	0	0	14	1	1	100	0	0	0	0	0	1	0	0	0	11	42
Less sway	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Visual + proprioceptive + vestibular	1																						
More sway	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
No difference [8]	1	0	1	0	0	0	0	0	14	1	1	100	0	0	0	0	0	1	0	0	0	11	42
Less sway	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	

The values indicate the number of positive scores assigned to each group of studies.
1 indicates reliability of outcome measures; 2, clear presentation of balance assessment; 3A, study controls for age; 3B, study controls for gender; 3C, study controls for height; 3D, study controls for body mass; 3E, study controls for physical activity; 4, use of appropriate statistical tests; 5, adequate sample size; 6A, adequate information regarding age; 6B, adequate information regarding gender; 6C, adequate information regarding height; 6D, adequate information regarding body mass; 6E: adequate information regarding physical activity; 6F, adequate information regarding type of LBP; 6G, adequate information regarding duration of LBP; 6H, adequate information regarding severity of LBP; 6I, adequate information regarding level of disability.

patients scored a lower pain intensity on VAS in studies showing no group difference (mean 3.0 and range 1.5–5.1) [10,31,32,40,45] compared to the studies showing more sway in patients (mean 4.9, range 2.5–6.1) [12,38,40,41]. However, an independent t-test revealed no significant difference ($p = 0.11$). Similarly, the duration of pain was not significantly different ($p = 0.89$) between the studies reporting no difference (mean 5.2 years, range 2.5–10.9 years) [10,31–33,40,45] and those reporting increased sway in patients (mean 4.8 years, range 0.25–10.6 years) [28,34,40]. The disability level measured by the Oswestry Disability Index, was not significantly different ($p = 0.38$) between the studies finding (mean 28.6, range 12.6–38.4) [12,38,40] and those not finding an effect of LBP (mean 21.5, range 14.5–34.8) [10,31–33,40,45]. Another suggestion could be that the inconsistency is related to the type of LBP. However, non-specific LBP was not less frequently included in the studies with a positive result (9/12, 75%) compared to those without a positive result (7/9, 78%).

Also when postural sway was assessed with perturbed visual information, no significant difference was obtained between the two groups of studies in terms of level of pain as measured on VAS (no difference: mean 2.5, range 1.5–3.8 [31,32,45]; changed sway: mean 4.9, range 2.6–6.1 [10,12,41]; $p = 0.15$) and duration of pain (no difference: mean 3.8 years, range 2.5–5.2 years [31–33,45]; changed sway: 10.9 years [10]). Similarly, the level of disability as measured by Oswestry Disability Index was not significantly different ($p = 0.18$) between the two groups of studies (no difference: mean 15.8, range 14.5–18.4 [31–33,45]; changed sway: mean 34.9, range 31.3–38.4 [10,12]; $p = 0.1$). Non-specific LBP was included in 5 out of 8 (63%) studies reporting and 7 out of 7 (100%) studies not reporting an effect.

4. Discussion

Inconsistent results were found, with many studies showing increased sway in LBP, similar numbers showing no effect of LBP and a few studies showing a negative effect on sway, regardless of the experimental condition. This overall conclusion contradicts that of Ruhe et al. [9] who concluded that more sway occurs in subjects with non-specific LBP compared to subjects without LBP. An explanation of the discrepancies between these two reviews is the fact that Ruhe et al. combined all experimental conditions (i.e. conditions with and without sensory manipulations) considering at least one significant effect in one of the conditions to reflect a positive finding. In the present study, we performed a more extensive comparison in which we compared postural sway in LBP subjects compared to non-LBP subjects during different sensory manipulations conditions separately. Due to the complex relationship of LBP and postural balance, this extensive comparison seems more informative, but more importantly it avoids type 1 errors due to multiple testing in the original studies.

Methodological differences between included studies may account for some of the inconsistencies and several potential explanations were scrutinized. Between-group differences may become more evident with increased difficulty of experimental conditions, increased sample size, use of more reliable COP measures, and with including patients with more severe LBP. No support was found for task difficulty as a factor underlying the detection of differences between patients and controls, as postural sway with sensory manipulations did not show more consistent differences than without manipulations. Sample size, surprisingly, tended to be larger in studies not showing an effect. This may indicate either stricter inclusion leading to more homogeneous groups or more strict experimental control in the smaller studies leading to a higher sensitivity. There was no clear difference in reliability of the dependent variables between studies finding and not finding a difference in postural sway between patients and controls. Finally, severity of LBP tended to be somewhat higher in the studies that did find increased sway in LBP patients. On the other hand, many of the studies finding increased sway did not adequately account for potential confounders such as age and body height and mass.

Other differences between studies may have played a role, but could not be verified due to a lack of sufficient information. For example, foot position and instructional set have an impact on postural sway. Very few studies [10,31,41,42,46] provided information regarding the standardization of foot position. Similarly, few authors [13,31–33,36–38,44] reported the instructions given to the participants during the task of quiet stance. "Stand as still as possible" was the most commonly used instruction. Instructional set has a profound effect on sway behavior with sway amplitude being substantially smaller when subjects were asked to keep their sway minimal compared to natural standing [49].

Increased sway in LBP was found in the majority of studies in the experimental conditions addressed and several of these studies were of good quality, without any indications of potential bias. Therefore, it appears that postural sway is increased in some LBP patients, but not in all, and it may actually be reduced in some. This may suggest that competing factors (e.g. fear of pain and pain itself) influence postural sway. Although such an explanation would remain hypothetical, we suggest that competing effects of pain and fear of pain may play a role. A decrease in force steadiness has been shown to occur with experimentally induced back pain [50] as well as in clinical low back pain [51,52], and might be a cause of increased sway. In addition, nociceptive afference has negative effects on proprioceptive feedback from muscle spindle afferents [53], which may also contribute to increased postural sway. An association between pain intensity and postural sway [54] provides support for a proposed direct effect of pain on postural sway. Conversely, pain-related fear of movement might reduce postural sway through a more rigid postural control strategy, i.e. through an increase in co-contraction levels and/or feedback gains [55], as an effect of arousal. While we are not aware of direct evidence regarding fear of pain, experiments using height to induce fear of movement [56,57] and experiments using images with negative valence [58,59] support the assumed mechanism.

The studies of Mok et al. [42] and Salavati et al. [43] showed reduced sway in LBP. In these two studies, patients experienced quiet low levels of pain or even no pain at the time of testing. According to the above suggestion, to overcome the disturbing effect of pain on postural control, patients may attempt to restrict their movement, which may, however, be more successful in the remission period. This explanation was also provided by van Dieën et al. [60] to explain the finding that patients with a recent history of LBP showed a lower sway amplitude in unstable sitting than individuals with current and without LBP.

Different neural components including sensory, motor and higher-cognitive processes have been proposed to have significant contribution in normal postural control. While most of the included studies investigated the role of sensory feedback on balance performance of patients with LBP, little [43,61] is known about the role of cognition in postural control of LBP. Given the changes in information processing in LBP [40], one may speculate that the influence of a secondary attention demanding task on sway might be different in LBP compared to healthy individuals. Therefore, dual-tasking can be used in future studies on balance performance in LBP. Furthermore, postural sway of LBP patients has been assessed mostly by linear measures of COP variability. Few studies [60,62] have investigated the nonlinear dynamical pattern of sway in LBP. Further analysis of postural sway by nonlinear methods might reveal differential responses of LBP and healthy people to sensory and cognitive manipulations more consistently.

In conclusion, the present review indicates that across conditions with different manipulations of sensory information, differences in postural sway between patients with LBP and healthy subjects are inconsistently reported. Given the fact that increased sway in LBP was reported by a majority of studies, some of good quality, it is concluded that postural sway is increased in some but not all patients with LBP.

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Conflict of interest

We are not aware of any conflicts of interest that may have affected the outcomes of our study.

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